Black Hole Outflows

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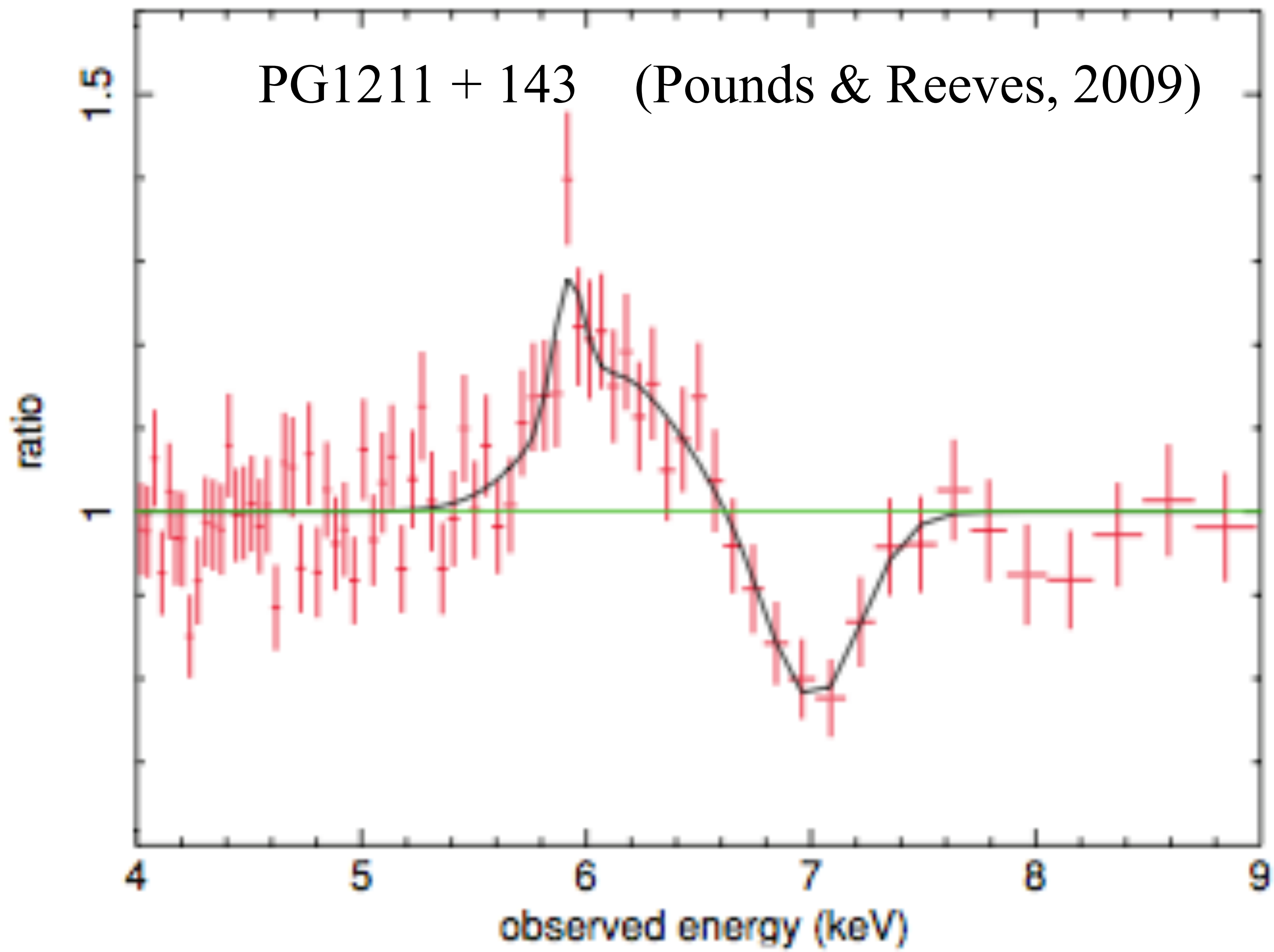
Rome, March 2011



P Cygni profile of iron K- alpha: *outflow* with $v \simeq 0.1c$

Pounds et al., 2003; King & Pounds, 2003: $v \sim 0.1c - 0.3c, \quad \xi \sim 10^4$

measured ionization parameter $\xi = \dfrac{L_i}{NR^2} \sim 10^4$

=> mass outflow rate

$$\dot{M}_{\rm out} = 4\pi b m_p N R^2 v \sim 1 {\rm M_\odot\, yr^{-1}} \sim \dot{M}_{\rm Edd}$$

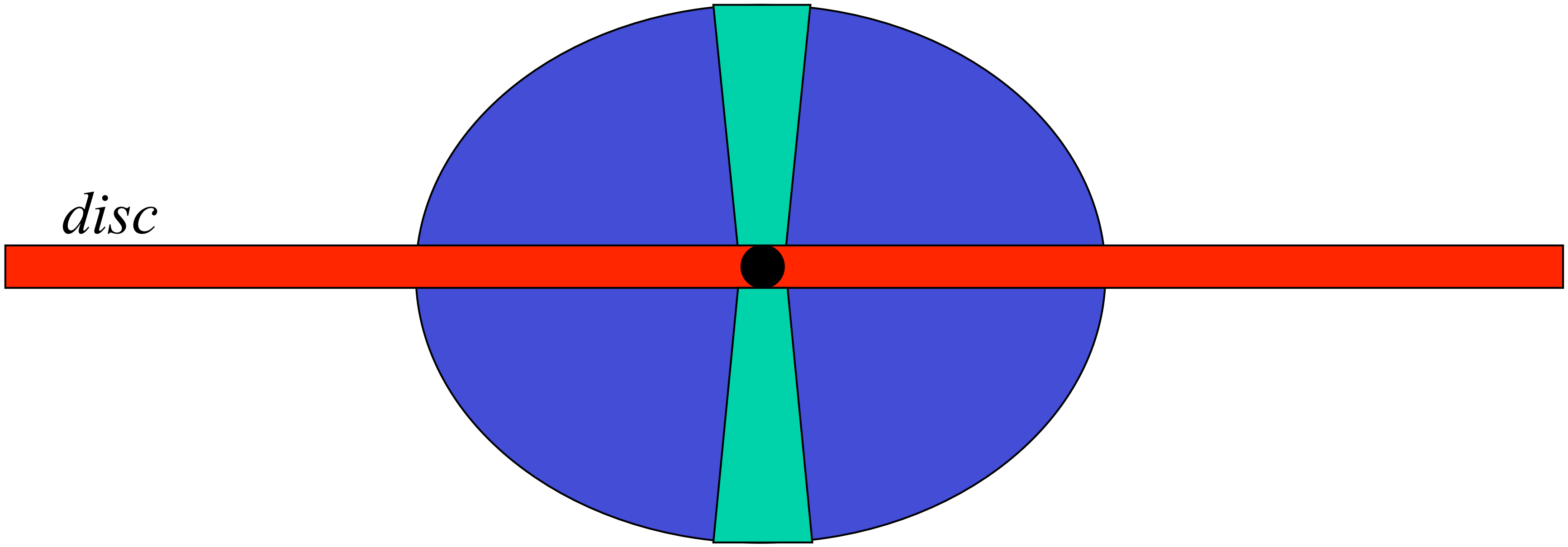
=> momentum outflow rate

$$\dot{M}_{\rm out} v \simeq 0.1 \dot{M}_{\rm Edd} c \simeq \eta \dot{M}_{\rm Edd} c = \frac{L_{\rm Edd}}{c}$$

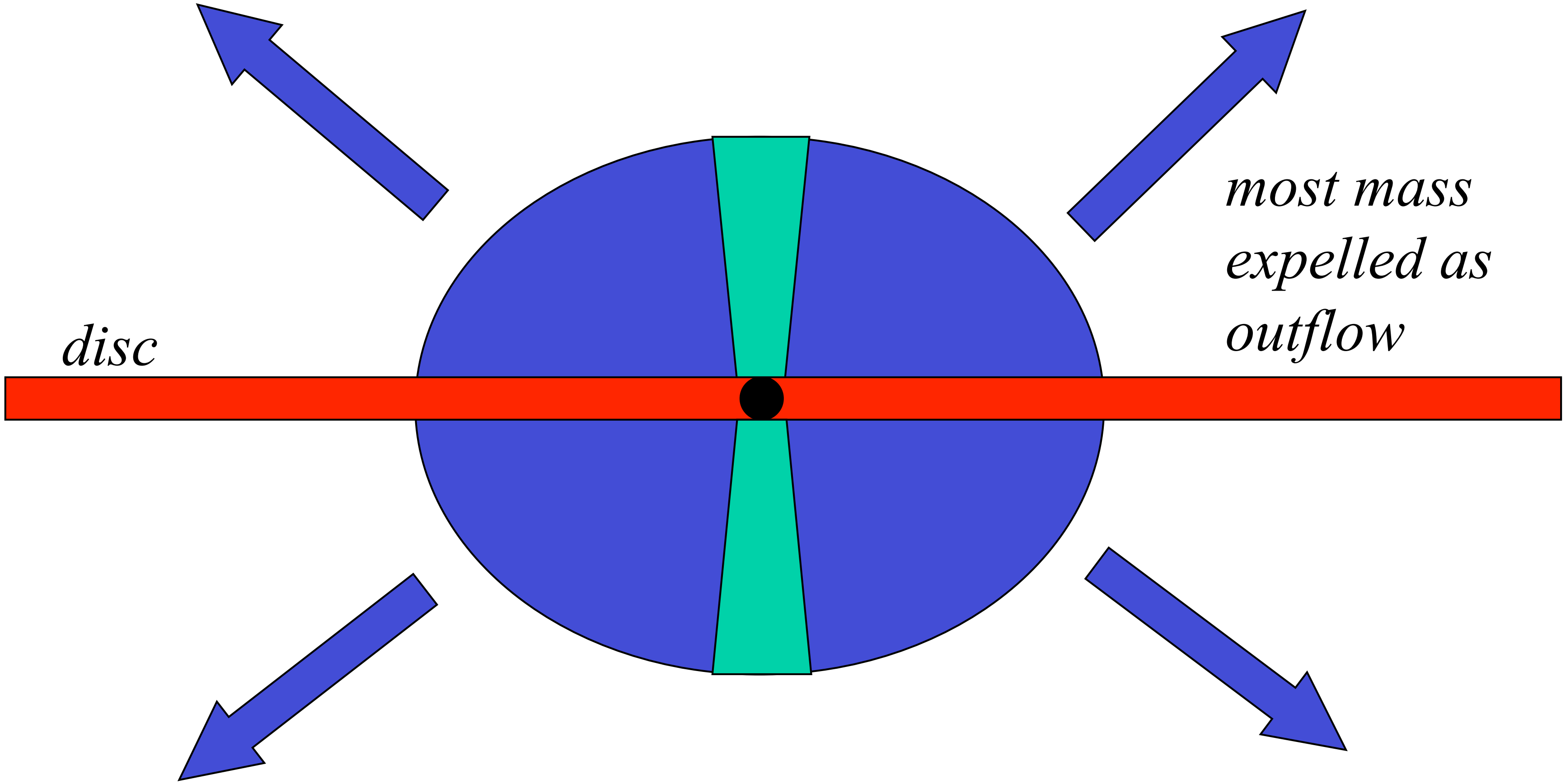
=> *photons scatter ~ once before escaping*: Eddington outflow has $\tau \sim 1$

Tombesi et al., 2010a,b: > 35% of a sample of 50 AGN show similar outflows: solid angle factor $\quad b = \Omega/4\pi > 0.6$

Super-Eddington Accretion



Super-Eddington Accretion



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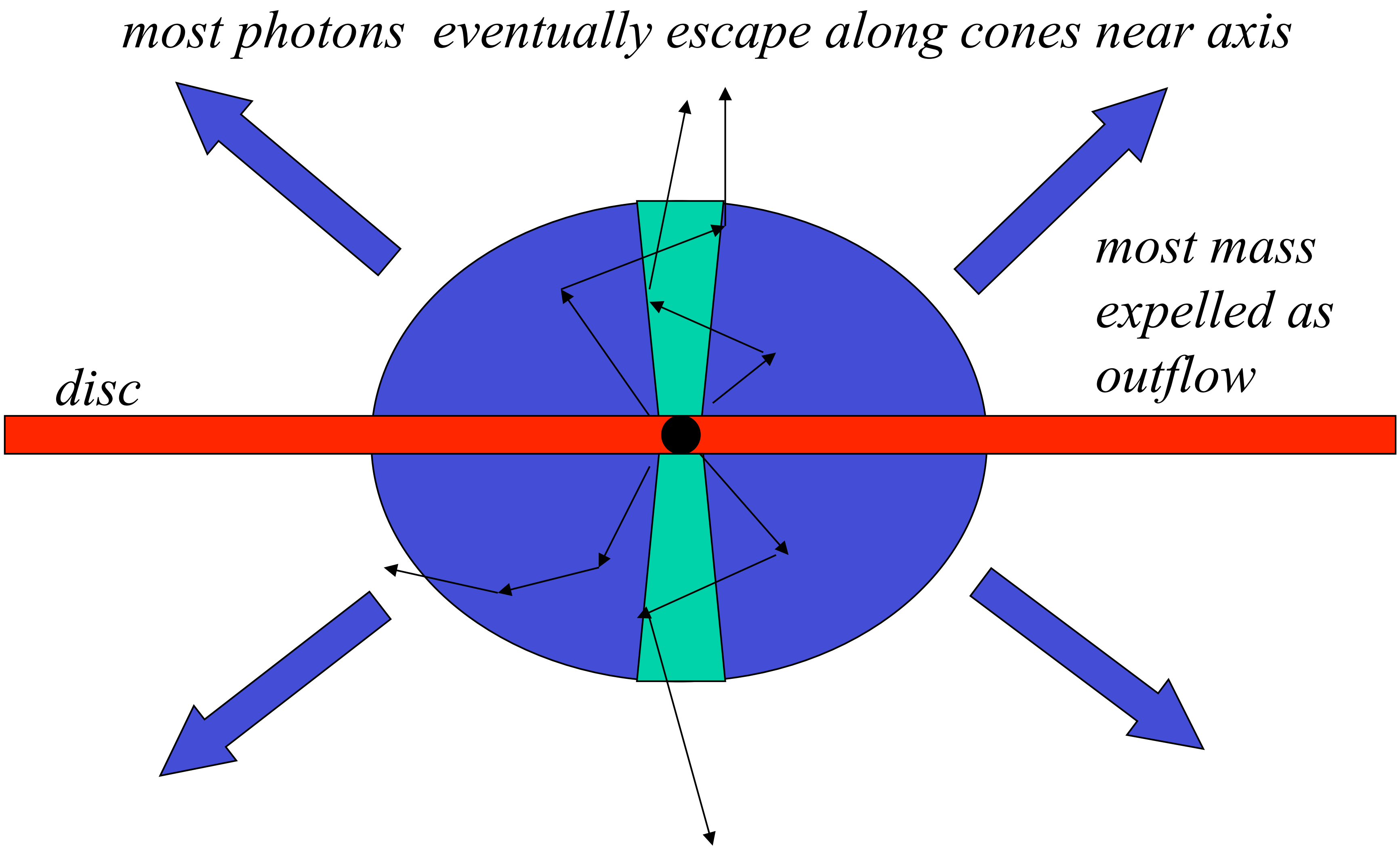

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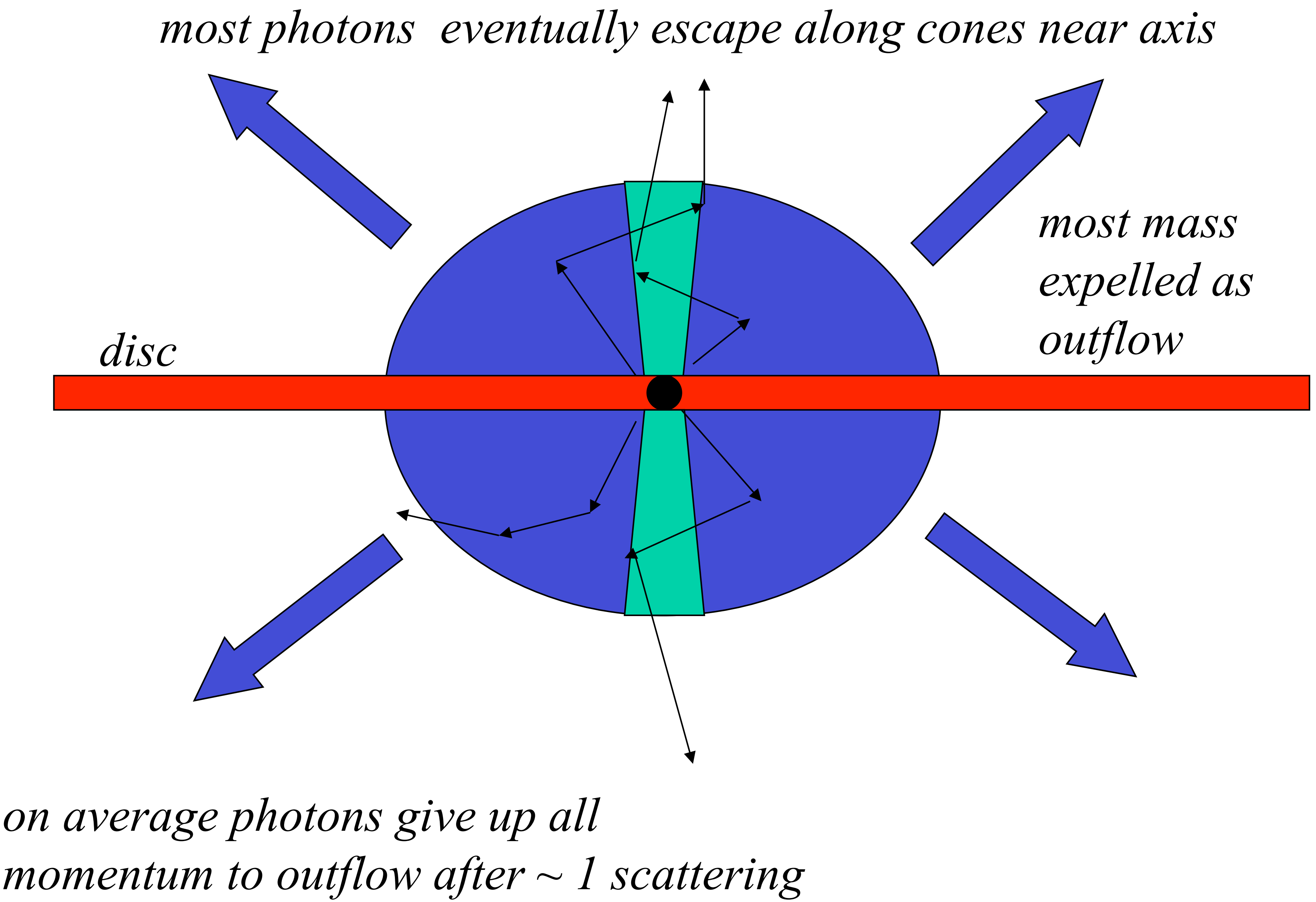
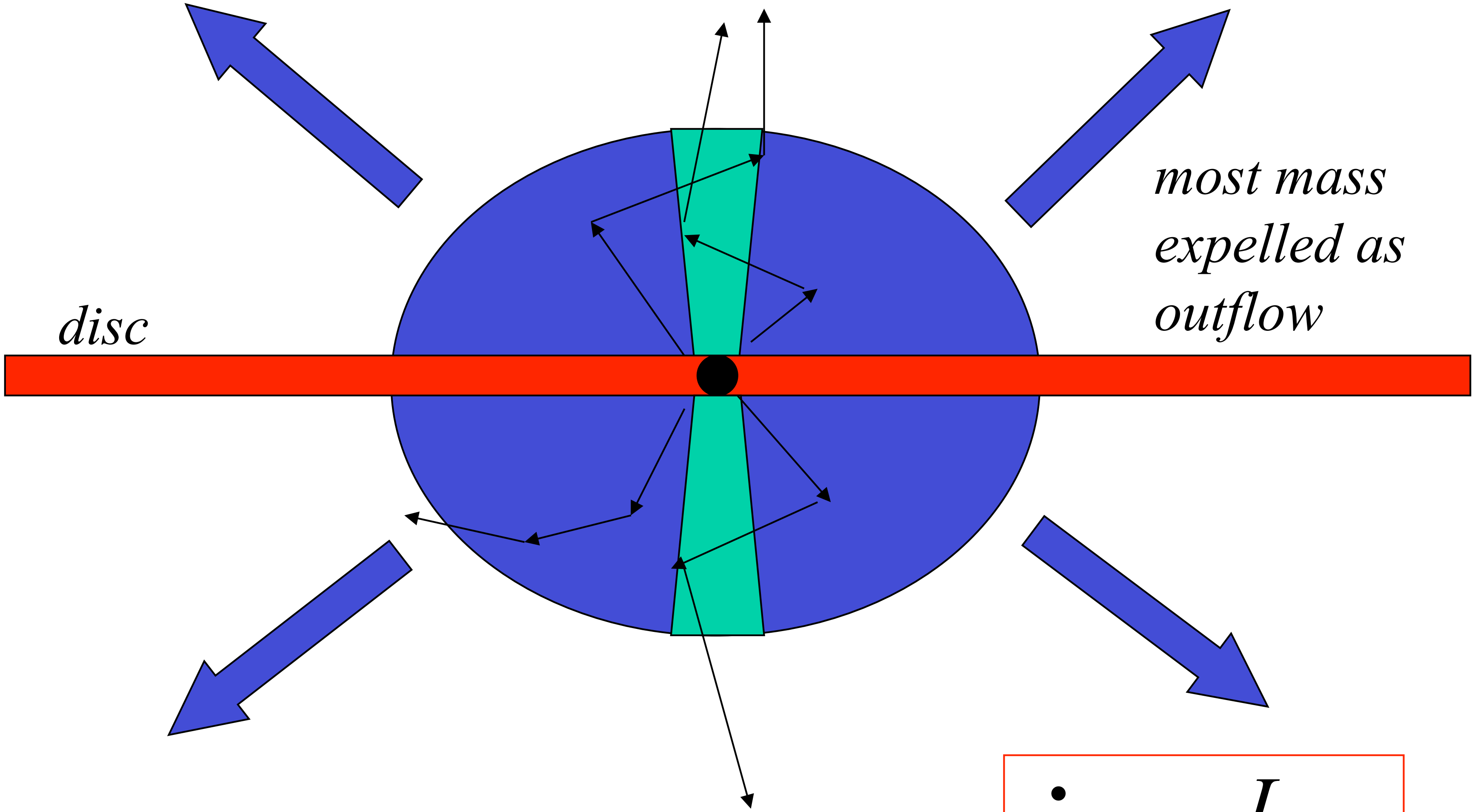


Super-Eddington Accretion

most photons eventually escape along cones near axis



most mass expelled as outflow

on average photons give up all momentum to outflow after ~ 1 scattering

$$\boxed{\dot{M} v \approx \frac{L_{Edd}}{c}}$$

conversely if we *assume* Eddington outflow, then mass and momentum conservation =>

$$v \sim \eta c, \quad \xi \sim 10^4$$

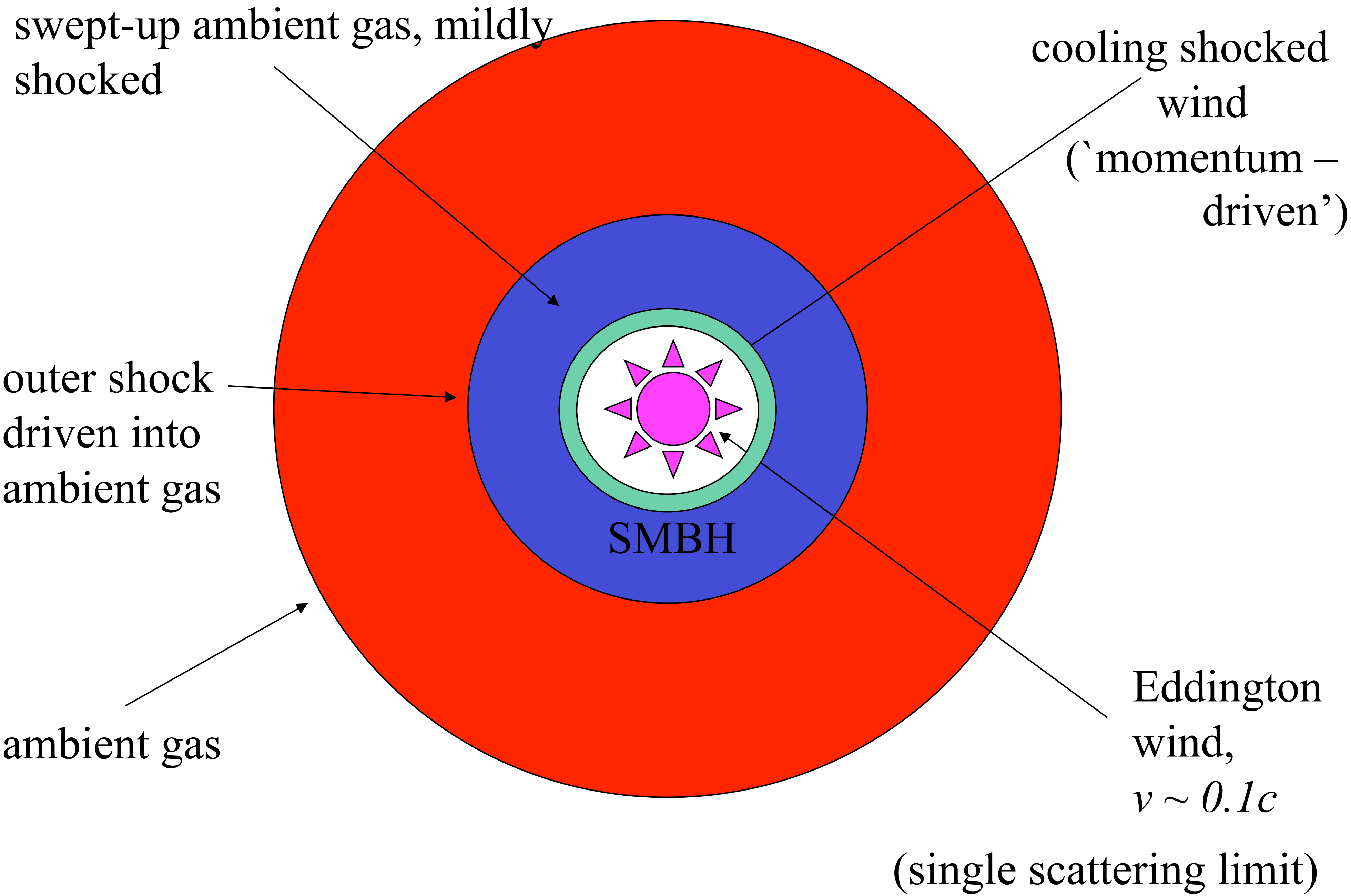
Eddington outflow $\longleftrightarrow$ X—ray lines with $v \sim 0.1c$

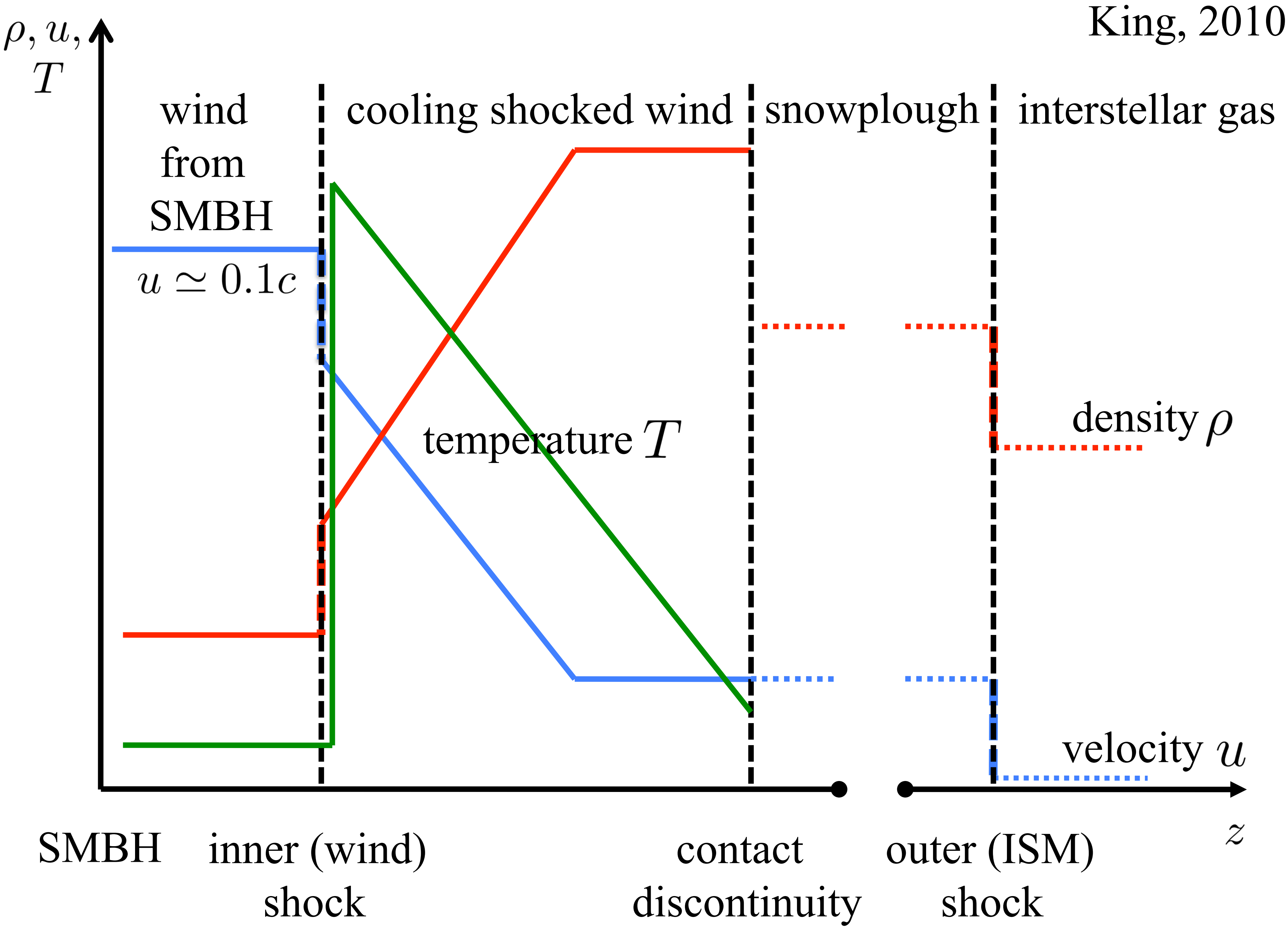
effect on galaxy must be significant

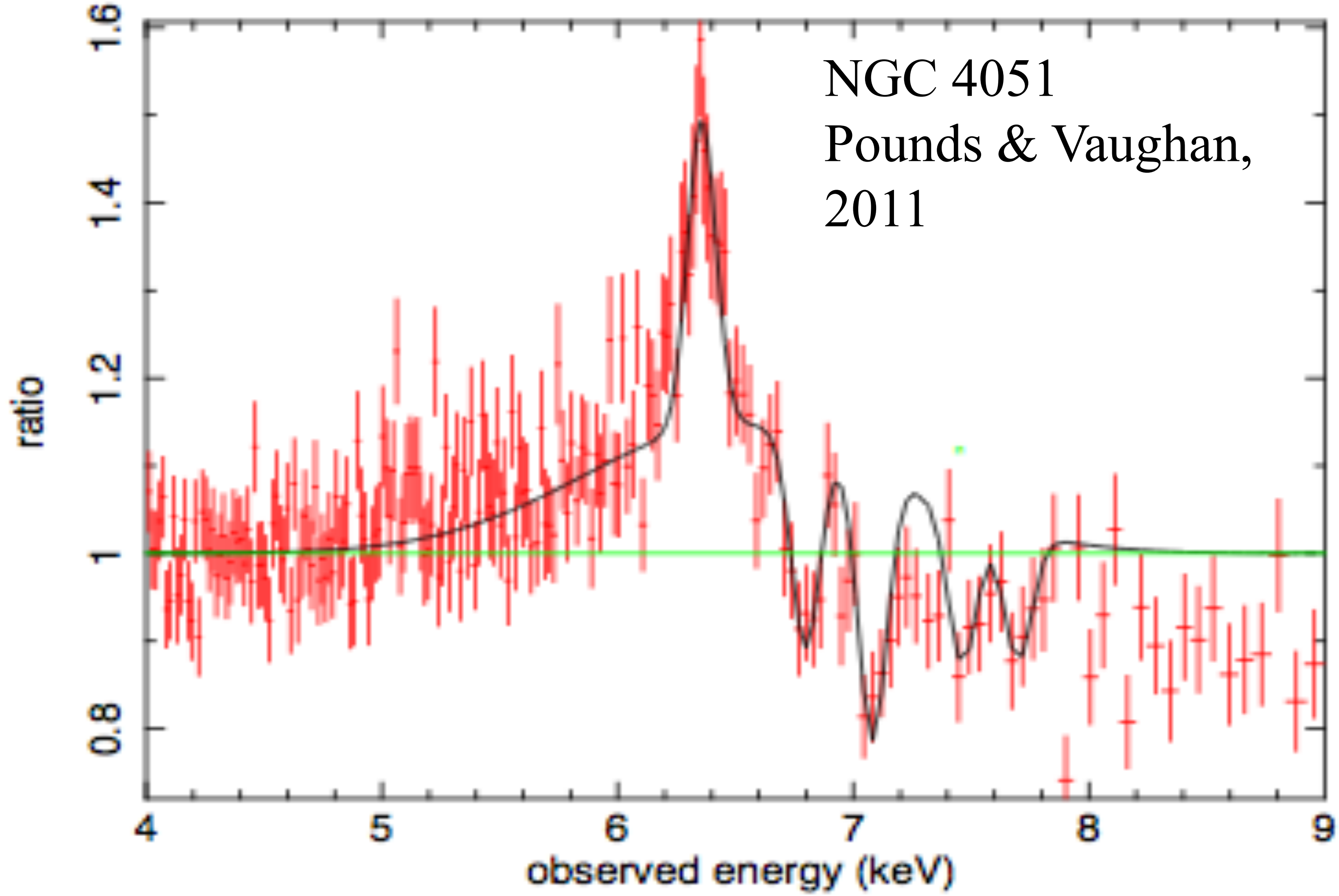
SMBH binding energy $\eta M c^2$

exceeds bulge binding energy $\eta M_b \sigma^2$

shock pattern near AGN




King, 2010
ρ, u, T
wind from SMBH
$u \simeq 0.1c$
cooling shocked wind
snowplough
interstellar gas
temperature T
density ρ
velocity u
z
SMBH
inner (wind) shock
contact discontinuity
outer (ISM) shock



evidence for shock structure: other velocity components are present

evidence for cooling shock

ionization parameter decreases with outflow velocity
as required by mass conservation

$$\dot{M}_{\rm out} \propto \frac{L_i v}{\xi} = {\rm const}$$

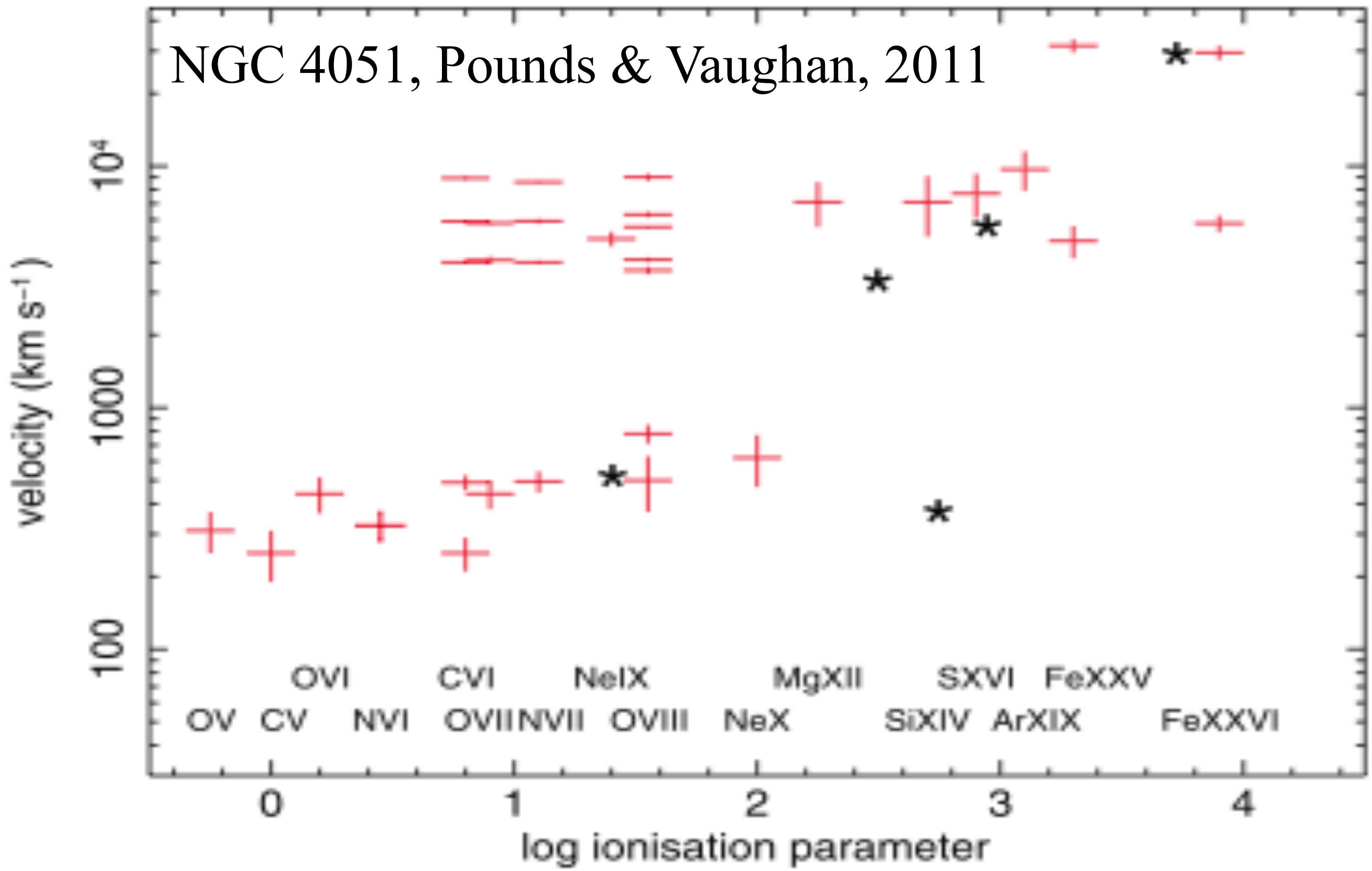


Figure 8. Outflow velocities derived from the Gaussian fitting plotted against the optimum ionization parameter for each parent ion stage. Also shown by asterisks are the parameters of the four photoionized absorbers derived from XSTAR modelling of the RGS absorption spectra, together with a velocity/ high-ionization point to represent the putative pre-shock wind.

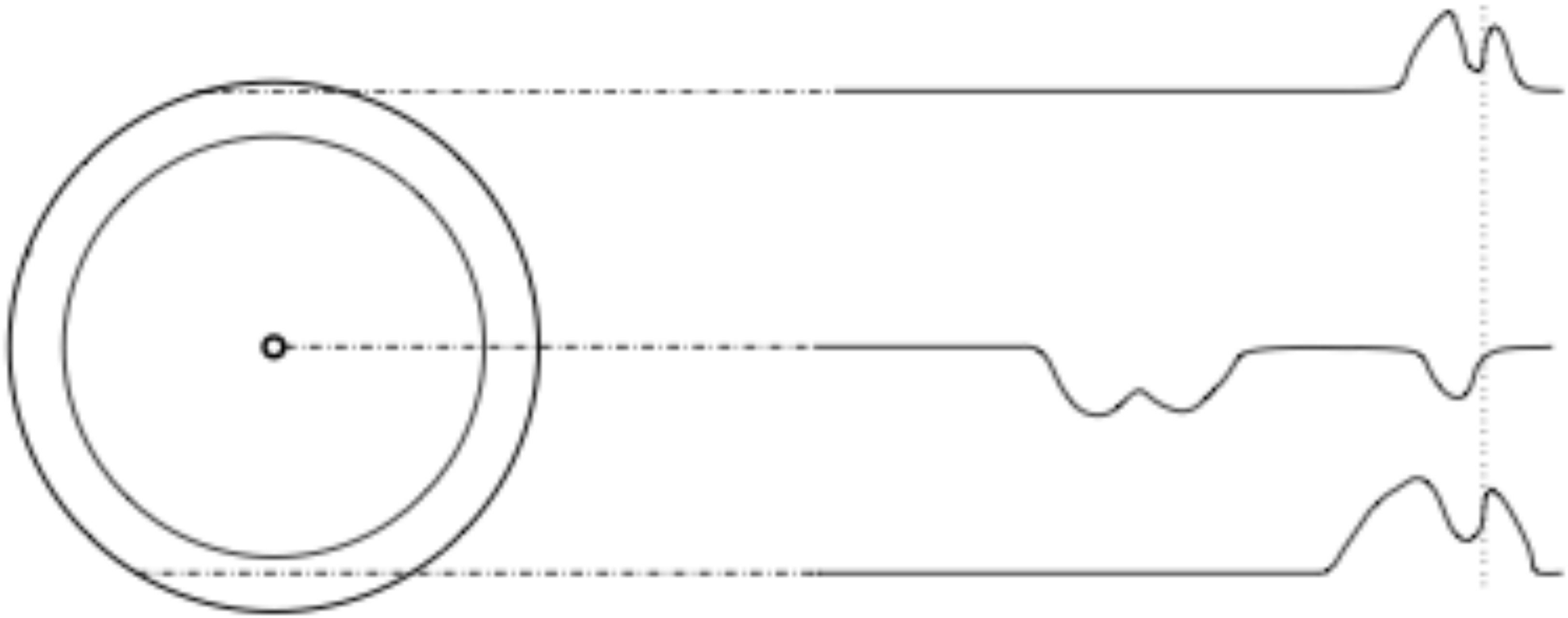
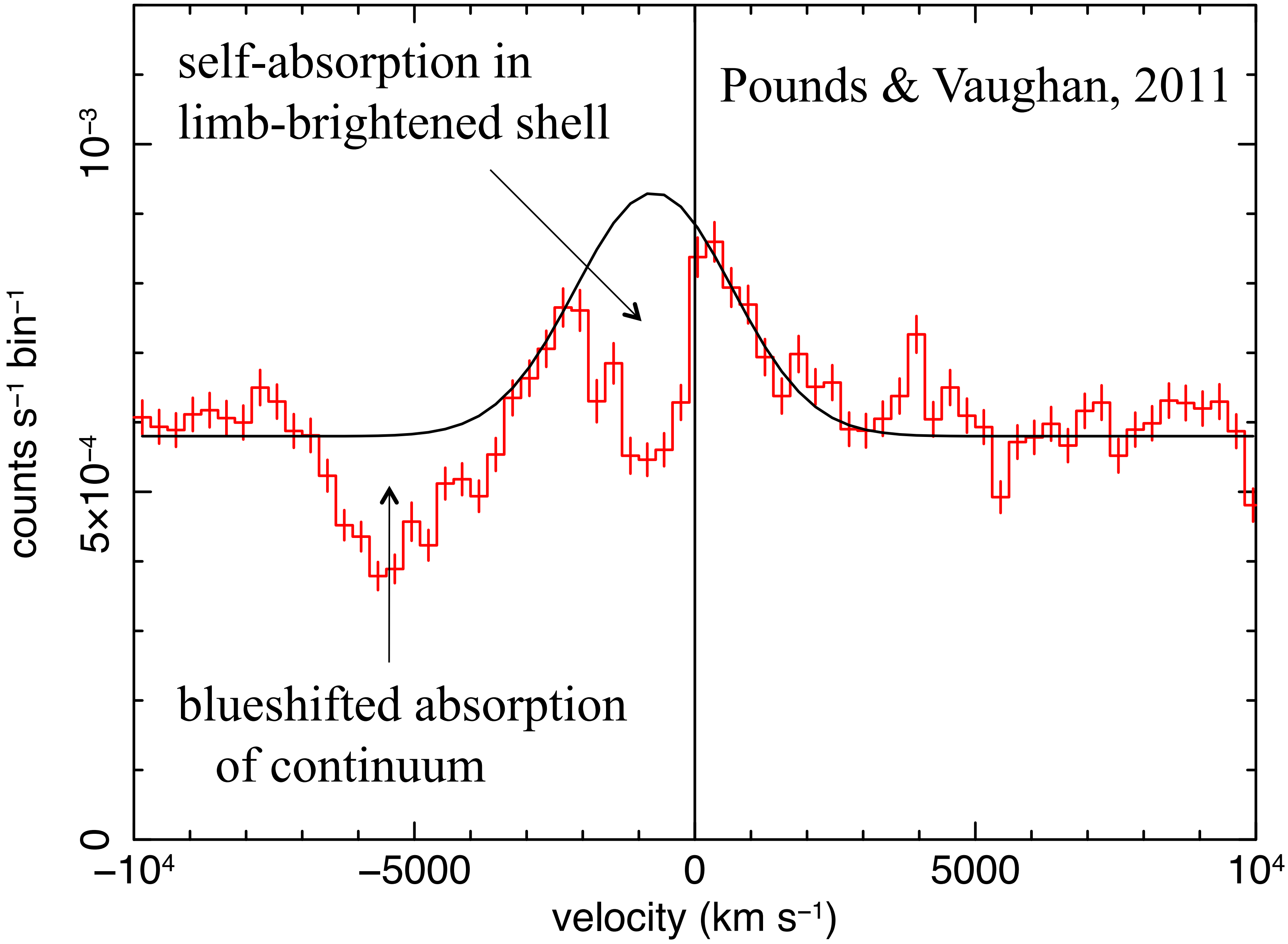


Figure 10. Sketch showing the origin of separate absorption spectra, in the continuum by line of sight to the AGN and by self-absorption in the soft X-ray emission from a limb-brightened shell.

Pounds & Vaughan, 2011



O VIII Lα velocity profile in PG1211+143

effect on galaxy: M – sigma relation

(simple derivation)

matter originally distributed so that

$$\frac{GM_{tot}(R)}{R} = 2\sigma^2$$

with

$$\frac{GM_{gas}(R)}{R} = 2 f_g \sigma^2 \qquad (f_g \approx 0.16)$$

at radius R total *weight* of shell is

$$\frac{GM_{tot}M_{gas}}{R^2} = \frac{4f_g\sigma^4}{G}$$

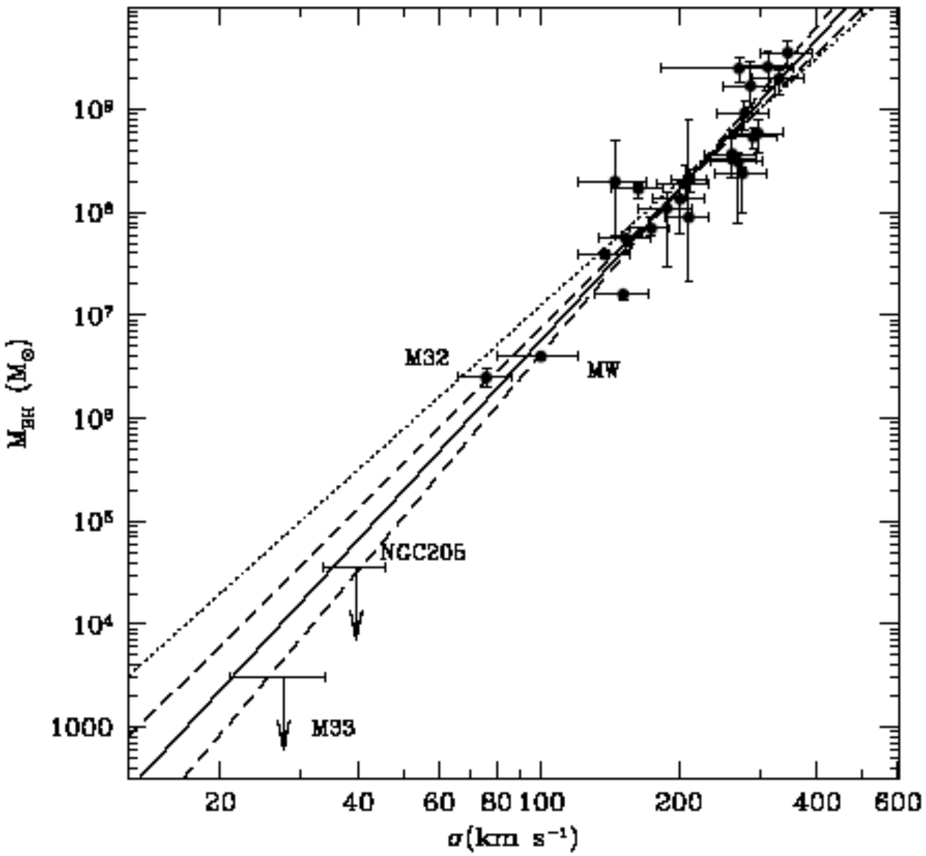
BH mass grows until Eddington thrust $\frac{L_{\rm Edd}}{c}$ matches this weight, i.e.

$$\frac{4\pi GM_{BH}}{\kappa} = \frac{4f_g\sigma^4}{G}$$

or

$$\boxed{M_{BH} = \frac{f_g\kappa}{\pi G^2}\sigma^4}$$ (King, 2003; 2005)

NB: *no free parameter*



$$M = 2\times10^{8}\sigma_{200}^{4}M_{\Theta}$$

relation is *upper limit* to M for given σ (Bacheldor, 2010)

(need to resolve SMBH sphere of influence $R_{\rm inf} = 2GM/\sigma^2$)

AGN black holes should be *below* this limit

SMBH – host connection

SMBH in every large galaxy, grown by luminous accretion (Soltan)

but only a small fraction of galaxies are AGN

➔ *SMBH should grow at ~ Eddington rate in AGN*

AGN should show outflows

AGN black holes should be underweight

NB: many BH mass estimates *assume* $M - \sigma$!

-- tendency to *overestimate* mass and *underestimate* Eddington factor

frequency of Eddington outflows

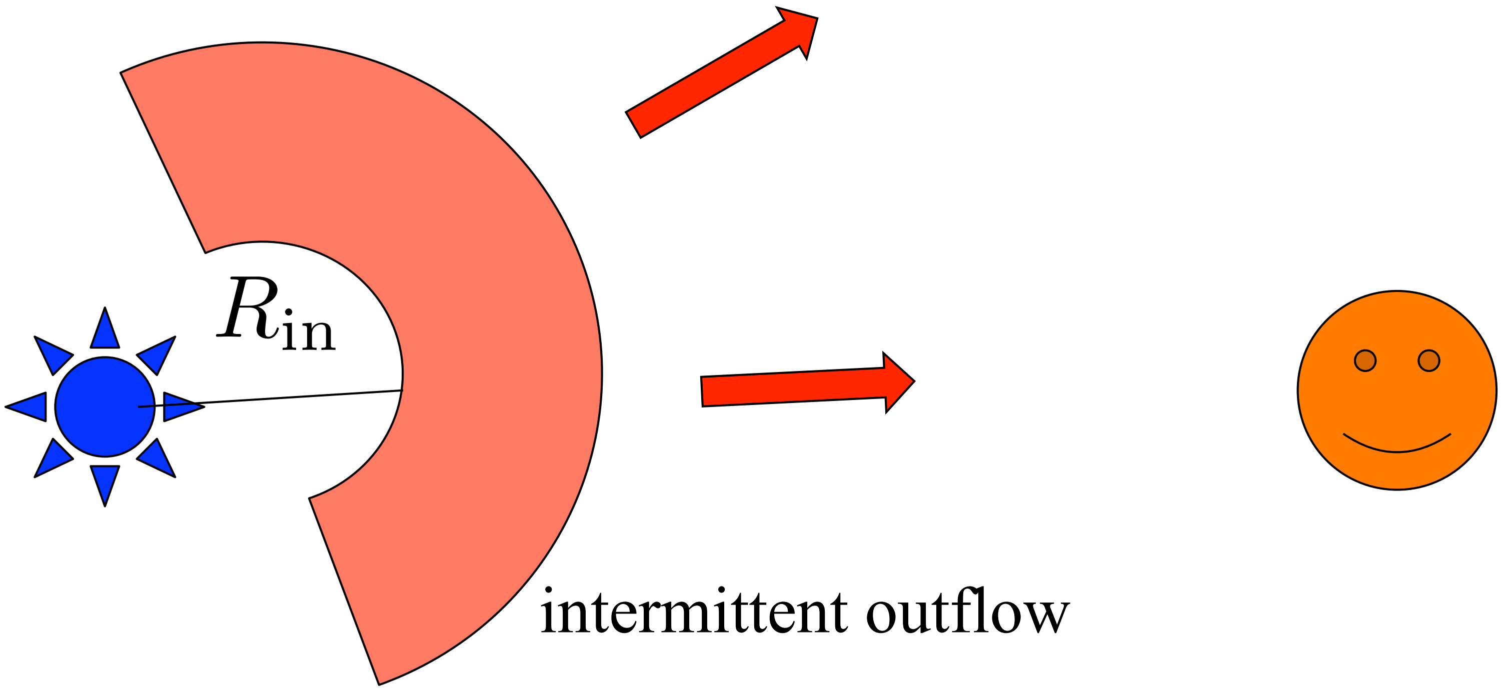
Tombesi et al 2010 a, b:

22/42 radio—quiet AGN, 3/5 BLRGs show outflows with

$$v \sim 0.1c - 0.3c, \quad \xi \sim 10^4$$

and hence $\dot{M}_{\rm out} \sim 1 - 10 M_{\odot}\,{\rm yr}^{-1}$, with very large momentum rates

high frequency ➔ solid angles large, $b \sim 0.5 - 1$: $\sim$ 50% of sample have super—Eddington episodes with significant duty cycles



observed X—ray column fixed by inner boundary of flow $R_{\rm in}$

$$N_{\rm H} \simeq \frac{10^{24}\dot m^3}{b\eta_{0.1}^2 (R_{\rm in}/100R_s)}\ {\rm cm}^{-2}$$

so if outflow stopped a time $t_{\rm off}$ ago, we have

$$t_{\rm off} \simeq 0.2\frac{\dot m^3 M_8}{b\eta_{0.1}^2 N_{23}}\ {\rm yr}$$

recent!

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X-ray outflows are key to SMBH-galaxy formation link